MOTOR DRIVE METHOD AND MOTOR DRIVER

BACKGROUND OF THE INVENTION

The present invention relates to motor drive technology, and more particularly, to a motor drive technology of a pulse width modulation (PWM) system.

As PWM drive systems for a brushless motor, a triangular wave slicing system and a peak current detecting system are known. In the triangular wave slicing system, a coil current is made to flow through a detection resistance, and the difference between a voltage generated at the detection resistance and a torque command voltage is output as a slice level by an error amplifier. A triangular wave having a constant period is sliced with the slice level, to determine the time period (ON period) during which the current flows to the coil. In the peak current detecting system, which uses no error amplifier, supply of a current to a coil is halted when the voltage generated at the current detection resistance, through which the coil current flows, reaches the torque command voltage, and a regenerative current mode is started.

FIG. **18** is a block diagram of a conventional motor driver of the peak current detecting method. Referring to FIG. **18**, Hall sensors **21A**, **21B** and **21C** detect the position of a rotor of a motor **10** and output the detection results to a position detection circuit **22** as Hall sensor outputs **S11**, **S12** and **S13**, respectively. The position detection circuit **22** determines position signals **S21**, **S22** and **S23** based on the Hall sensor outputs **S11**, **S12** and **S13**, respectively, and outputs the signals to a phase switch circuit **93**. The position signals **S21**, **S22** and **S23** are signals obtained by shifting the phase of the Hall sensor outputs **S11**, **S12** and **S13** by 30°.

The phase switch circuit **93** determines the phases of currents to pass according to the position signals **S21**, **S22** and **S23**. For easy measurement of the phase currents, the

phase switch circuit **93** blocks flow of one of three phase currents. A Logic control circuit **95**, set upon receipt of a reference pulse **PI**, controls supply of currents to the motor **10** by changing the level of signals output to the phase switch circuit **93**. The reference pulse **PI** is a periodical pulse.

FIG. **19** is a graph showing changes with time of phase currents for the motor driven by the motor driver of FIG. **18**. In FIG. **19**, phase currents **I1**, **I2** and **I3** in U, V and W phases, respectively, are shown, and currents flowing from drive transistors **1** to **6** toward the motor **10** are considered positive. As is found from FIG. **19**, there is always one phase current that becomes zero, and thus there occurs sharp change of any of the phase currents every electrical angle of 60°.

Assume that the logic control circuit **95** has been set with the reference pulse **PI**. The phase switch circuit **93** turns ON only the W-phase upper side drive transistor **5** and the U-phase lower side drive transistor **2**, for example. In this state, a current flows to a current detection resistance **7** via a W-phase coil **13** and a U-phase coil **11**. The magnitude of this current can therefore be detected as the voltage generated at the current detection resistance **7**. Since this current flows through the inductive coils, the current gradually increases after the conduction of the drive transistors **2** and **5**.

With increase of the current, the voltage generated at the current detection resistance **7** increases, and when it reaches a torque command voltage **TI**, the level of the output of a comparator **96** changes, causing the logic control circuit **95** to be reset. The reset logic control circuit **95** reverses the level of a signal output to the phase switch circuit **93**. On receipt of this signal, the phase switch circuit **93** turns OFF the drive transistor **2**.

The time period from the setting of the logic control circuit **95** until the reset thereof corresponds to the "on" period of switching operation. After the reset of the logic control circuit **95**, the current flowing through the coils **11** and **13** still attempts to continue

the flow, and this causes a regenerative current to flow through a diode **1D** existing between the source and drain of the drive transistor **1**. Since the regenerative current does not pass through the current detection resistance 7, the voltage generated at the current detection resistance 7 is zero during the flow of the regenerative current.

The regenerative current gradually decreases. However, upon receipt of the reference pulse **PI**, the logic control circuit **95** is set again, and the phase switch circuit **93** turns ON the drive transistor **2**. This operation is repeated until the phase switch circuit **93** switches the phases of currents to pass. In this way, as a result of the alternate flow of the drive current flowing when the logic control circuit **95** is set and the regenerative current flowing when the logic control circuit **95** is reset, a phase current roughly corresponding to the torque command voltage **TI** is allowed to flow through a predetermined coil.

FIG. **20** is a graph showing the current detection resistance voltage (motor current detection signal) **MC** and the V-phase and W-phase currents **I2** and **I3** at and around time t = tz in FIG. **19**, obtained by enlarging the time axis. In FIG. **20**, a period **T91** is a time period during which a drive current of the U-phase and V-phase currents flows. This drive current flows through the current detection resistance 7. A period **T92** is a time period during which the U-phase and V-phase currents flow as a regenerative current. A period **T93** is a time period during which a drive current of the U-phase and W-phase currents flows. This drive current flows through the current detection resistance 7. A period **T94** is a time period during which the U-phase and W-phase currents flow as a regenerative current.

The conventional motor driver shown in FIG. **18** has the following problem. The phase currents sharply change as shown in FIG. **19**. For this reason, when the phase currents are switched, vibration of the motor and generation of electromagnetic noise tend to occur.

To avoid the above problem, the phase currents may be controlled not to change sharply. However, to detect and control a plurality of phase currents, it is necessary to provide current detection resistances in the same number as the number of phases. It is difficult to incorporate the current detection resistances in an integrated circuit. Therefore, as the number of the current detection resistances is greater, the scale of the device is larger and the cost is higher.

In addition, the properties of resistances generally have variations. Therefore, in the case of using current detection resistances for the respective phases, the current detection properties vary every phase. For example, when two phase currents are actually the same in magnitude, the magnitudes of the detected currents may sometimes be different from each other.

SUMMARY OF THE INVENTION

An object of the present invention is driving a motor by controlling a plurality of phase currents not to change sharply, using current detection resistances smaller than the phase currents in number, to reduce vibration of the motor and electromagnetic noise.

Specifically, an inventive motor drive method is for a motor driver which has a plurality of output circuits each including an upper side switching element and a lower side switching element connected in series, and a current detection resistance connected in series with the plurality of output circuits in common for detecting a current supplied to the plurality of output circuits and which supplies a current to a motor from a connection point between the upper side switching element and the lower side switching element of each of the output circuits. The motor drive method includes the steps of: determining a position signal corresponding to the position of a rotor of the motor; selecting one switching element of one of the plurality of output circuits according to the position signal and

turning ON the selected switching element for a time period corresponding to a predetermined electrical angle; and repeatedly switching lower side switching elements of a plurality of output circuits among the remaining ones of the plurality of output circuits when the selected switching element is an upper side switching element, while repeatedly switching upper side switching elements of a plurality of output circuits among the remaining ones of the plurality of output circuits when the selected switching element is a lower side switching element, wherein in the switching step, the switching operation is controlled according to an input torque command signal and a voltage generated at the current detection resistance so that each of a plurality of periods obtained by dividing the time period corresponding to the predetermined electrical angle includes a first period in which one of the switching elements to be switched is turned ON and a second period in which another one of the switching elements is turned ON.

According to the invention, there are provided the first period in which a switching element is turned ON and the second period in which another switching element is turned ON. Therefore, phase currents equal to or larger than the current detection resistance in number can be controlled. This enables PWM control with no variation in magnitude of the phase currents. In addition, the phase currents are avoided from sharp change, and thus vibration of the motor and electromagnetic noise during the phase switch can be reduced.

Another motor drive method is for a motor driver which has an even number of output circuits that is four or more each including an upper side switching element and a lower side switching element connected in series, and a current detection resistance connected in series with the output circuits in common for detecting a current supplied to the output circuits, and which supplies a current to a motor from a connection point between the upper side switching element and the lower side switching element of each of the output circuits. The motor drive method includes the steps of: determining a position

signal corresponding to the position of a rotor of the motor; selecting one switching element of one of the output circuits according to the position signal, and, for a time period corresponding to a predetermined electrical angle, turning ON a pair of the selected switching element and a lower side switching element of the output circuit corresponding to a phase opposite to a phase corresponding to the output circuit including the selected switching element when the selected switching element is an upper side switching element, while turning ON a pair of the selected switching element and an upper side switching element of the output circuit corresponding to a phase opposite to a phase corresponding to the output circuit including the selected switching element when the selected switching element is a lower side switching element; and repeatedly switching each pair of any one of the lower side switching elements of a plurality of output circuits among the remaining ones of the output circuits and the upper side switching element corresponding to a phase opposite to a phase corresponding to the output circuit including said one lower side switching element when the selected switching element is an upper side switching element, while repeatedly switching each pair of any one of the upper side switching elements of a plurality of output circuits among the remaining ones of the output circuits and the lower side switching element corresponding to a phase opposite to a phase corresponding to the output circuit including said one upper side switching element when the selected switching element is a lower side switching element, wherein in the switching step, the switching operation is controlled according to an input torque command signal and a voltage generated at the current detection resistance so that each of a plurality of periods obtained by dividing the time period corresponding to the predetermined electrical angle includes a first period in which one pair of the switching elements are turned ON and a second period in which another pair of the switching elements are turned ON.

In the switching step of the motor drive method, the first period is preferably

started when a reference pulse is input, and is preferably terminated when the voltage generated at the current detection resistance reaches a target signal.

In the switching step of the motor drive method, upon receipt of the reference pulse, the first period is preferably started after all the switching elements to be switched have been turned OFF.

Still another motor drive method is for a motor driver which has a plurality of output circuits each including an upper side switching element and a lower side switching element connected in series, and a current detection resistance connected in series with the plurality of output circuits in common for detecting a current supplied to the plurality of output circuits, and which supplies currents to motor coils of a plurality of phases from a connection point between the upper side switching element and the lower side switching element of each of the output circuits. In this method, a period in which respective phase currents for the motor coils of the plurality of phases flow simultaneously is divided into pulse width modulation (PWM) control periods, and in each of the PWM control periods, a PWM control is performed by providing said each of the PWM control periods with a period in which the switching elements are selectively turned ON until a signal corresponding to the value of a current flowing each of the switching elements coincides with a signal obtained from the current detection resistance such that a current flowing through the current detection resistance is the same as a current passing through specific one of the upper and lower switching elements, and a period in which phase currents for phases other than a phase relating to the specific switching element are made in regenerative states.

An inventive motor driver having a plurality of output circuits each including an upper side switching element and a lower side switching element connected in series, for supplying a current to a motor from a connection point between the upper side switching

element and the lower side switching element of each output circuit, includes: a current detection resistance connected in series with the plurality of output circuits in common for detecting a current supplied to the plurality of output circuits; a position detection section for outputting a position signal corresponding to the position of a rotor of the motor; a phase switch circuit for selecting one switching element of one of the plurality of output circuits according to the position signal and turning ON the selected switching element for a time period corresponding to a predetermined electrical angle, and repeatedly switching lower side switching elements of a plurality of output circuits among the remaining ones of the plurality of output circuits when the selected switching element is an upper side switching element, while repeatedly switching upper side switching elements of a plurality of output circuits among the remaining ones of the plurality of output circuits when the selected switching element is a lower side switching element; and an ON-period control section for generating a switching control signal for controlling the switching operation by the phase switch circuit according to an input torque command signal and a voltage generated at the current detection resistance so that each of a plurality of periods obtained by dividing the time period corresponding to the predetermined electrical angle includes a first period in which one of the switching elements to be switched is turned ON and a second period in which another one of the plurality of switching elements is turned ON, and outputting the generated signal.

In the motor driver, the ON-period control section preferably includes: a torque signal generation circuit for obtaining, according to the torque command signal and the position signal, a first target signal corresponding to a target value of a current that should flow to the current detection resistance during the first period and a second target signal corresponding to a target value of a current that should flow to the current detection resistance during the second period, and outputting the target signals; a first comparator for

determining whether or not the voltage generated at the current detection resistance exceeds the first target signal and outputting the result; a second comparator for determining whether or not the voltage generated at the current detection resistance exceeds the second target signal and outputting the result; and a logic control circuit for generating the switching control signal according to a reference pulse for defining the period of the switching operation and the outputs of the first and second comparators and outputting the generated signal. The logic control circuit preferably generates the switching control signal so that the first period is terminated when the first comparator determines that the voltage generated at the current detection resistance has exceeded the first target signal and that the second period is terminated when the second comparator determines that the voltage generated at the current detection resistance has exceeded the second signal, and preferably outputs the generated signal.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of a motor driver according to a first embodiment of the present invention.

FIG. **2** is a graph showing target waveforms for respective phase currents for a motor in FIG. **1**.

FIG. **3** is a block diagram of an example of a torque signal generation circuit in FIG. **1**.

FIG. **4** is a graph showing signals related to a position detection circuit and a torque signal generation circuit.

FIG. **5** is a block diagram of an example of a logic control circuit in FIG. **1**.

FIG. **6** is a graph showing signals input/output into/from a logic control circuit and a comparator in FIG. **1**.

FIG. 7 is a graph showing phase currents in the motor driver of FIG. 1.

FIG. 8 is an illustration of routes of currents flowing through the motor during a period **T1**.

FIG. 9 is an illustration of routes of currents flowing through the motor during a period **T2**.

FIG. 10 is an illustration of routes of currents flowing through the motor during a period **T3**.

FIG. 11 is a block diagram of a motor driver according to a second embodiment of the present invention.

FIG. 12 is a circuit diagram of an example of an offset-added limiting circuit.

FIG. 13 is a graph showing phase currents and a signal for an ON-period control section in the motor driver in FIG. 11.

FIG. 14 is a graph showing waveforms of output currents of respective phases in driving a 3-phase motor such that the phase currents are sine waves.

FIG. 15 is a graph showing waveforms of output currents of respective phases in driving a 4-phase motor such that the phase currents are sine waves.

FIG. 16 is a graph showing waveforms of output currents of respective phases in driving a 6-phase motor such that the phase currents are sine waves.

FIG. 17 is a graph showing waveforms of output currents of respective phases in driving an 8-phase motor such that the phase currents are sine waves.

FIG. 18 is a block diagram of a conventional motor driver of the peak current detecting method.

FIG. 19 is a graph showing changes with time of phase currents for a motor driven by the motor driver of FIG. 18.

FIG. 20 is a graph showing a current detection resistance voltage (motor current

detection signal) and V-phase and W-phase currents at and around time t = tz in FIG. **19**, obtained by enlarging the time axis.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Hereinafter, preferred embodiments of the present invention will be described with reference to the accompanying drawings. In the following embodiments, the case where a motor driver drives a three phase brushless motor will be described as an example.

EMBODIMENT 1

FIG. **1** is a block diagram of a motor driver of the first embodiment of the present invention. The motor driver of FIG. **1** includes U-phase, V-phase and W-phase upper side drive transistors **1**, **3** and **5**, U-phase, V-phase and W-phase lower side drive transistors **2**, **4** and **6**, diodes **1D**, **2D**, **3D**, **4D**, **5D** and **6D**, a current detection resistance **7**, a Hall sensor circuit **21**, a position detection circuit **22**, a phase switch circuit **23**, a pre-drive circuit **24**, an amplifier **27**, a torque signal generation circuit **30**, a logic control circuit **40** and comparators **51** and **52**. A motor **10** includes a U-phase coil **11**, a V-phase coil **12** and a W-phase coil **13**. The torque signal generation circuit **30**, the logic control circuit **40** and the comparators **51** and **52** constitute an ON-period control section **100**. The Hall sensor circuit **21** and the position detection circuit **22** constitute a position detection section.

N-type metal oxide semiconductor (MOS) transistors are used as the drive transistors **1** to **6** in this embodiment. The anode and cathode of the diode **1D** are connected to the source and drain of the drive transistor **1**, respectively. Likewise, the diodes **2D** to **6D** are connected to the drive transistors **2** to **6**, respectively, in the same manner. The drains of the drive transistors **1**, **3** and **5** are connected to the power supply **VCC**, and the sources of the drive transistors **2**, **4** and **6** are connected to one terminal of

the current detection resistance 7. The other terminal of the current detection resistance 7 is grounded. The drive transistors **1** to **6** operate as switching elements.

The drive transistors **1** and **2** and the diodes **1D** and **2D** operate as a U-phase output circuit (half-bridge circuit), the drive transistors **3** and **4** and the diodes **3D** and **4D** operate as a V-phase output circuit, and the drive transistors **5** and **6** and the diodes **5D** and **6D** operate as a W-phase output circuit. The current supplied from the power supply **VCC** to these output circuits flows to the current detection resistance 7.

The source of the drive transistor **1** is connected to the drain of the drive transistor **2** and also connected to one terminal of the U-phase coil **11** of the motor **10**. The source of the drive transistor **3** is connected to the drain of the drive transistor **4** and also connected to one terminal of the V-phase coil **12** of the motor **10**. The source of the drive transistor **5** is connected to the drain of the drive transistor **6** and also connected to one terminal of the W-phase coil **13** of the motor **10**. The other terminals of the U-phase coil **11**, the V-phase coil **12** and the W-phase coil **13** are connected to one another.

Herein, the current flowing from the drive transistors **1** and **2** toward the U-phase coil **11** is called a U-phase current **I1**. Likewise, the current flowing from the drive transistors **3** and **4** toward the V-phase coil **12** is called a V-phase current **I2**, and the current flowing from the drive transistors **5** and **6** toward the W-phase coil **13** is called a W-phase current **I3**. Also, currents flowing from the drive transistors **1** to **6** toward the coils **11** to **13** are called source currents, while currents in the opposite direction are called sink currents. The direction of the source currents is assumed as the positive direction for all the phase currents. The coils **11** to **13** of the motor **10** are in Y connection. Therefore, the respective phase currents are equal to currents flowing through the corresponding coils.

The Hall sensor circuit **21** includes Hall sensors **21A**, **21B** and **21C**, which detect the position of a rotor of the motor **10** and output the detection results to the position

detection circuit **22** as Hall sensor outputs **S11**, **S12** and **S13**, respectively. The position detection circuit **22** determines position signals **S21**, **S22**, **S23** and **PS** based on the Hall sensor outputs **S11**, **S12** and **S13**, and outputs the signals **S21**, **S22** and **S23** to the phase switch circuit **23** and the signal **PS** to the torque signal generation circuit **30**.

The torque signal generation circuit **30** generates voltage signals **TS1** and **TS2** corresponding to a target value of a current to flow to the current detection resistance **7** based on the position signal **PS** and a torque command voltage (torque command signal) **TI**, and outputs the signals **TS1** and **TS2** to the positive input terminals of the comparators **51** and **52**, respectively. The amplifier **27** is connected to both terminals of the current detection resistance **7**, and outputs a motor current detection signal **MC** according to a voltage generated at the current detection resistance **7** to the negative input terminals of the comparators **51** and **52**.

The comparators **51** and **52** supply the respective comparison results of input signals to the logic control circuit **40** as the outputs **CP1** and **CP2**, respectively. The logic control circuit **40**, which also receives the reference pulse **PI**, generates switching control signals **F1** and **F2** for defining the time period during which the drive transistors **1** to **6** are kept ON, and outputs the signals to the phase switch circuit **23**.

The phase switch circuit **23** selects any of the drive transistors **1** to **6** to be turned ON based on the position signals **S21**, **S22** and **S23** and the control signals **F1** and **F2**, and sends instructions to the pre-drive circuit **24**. The pre-drive circuit **24** outputs signals to the gates of the drive transistors **1** to **6** according to the outputs of the phase switch circuit **23**, to control ON/OFF of the drive transistors **1** to **6**.

FIG. **2** is a graph showing target waveforms for the phase currents **I1** to **I3** for the motor **10**. The motor driver of FIG. **1** controls supply of currents to the motor **10** as shown in FIG. **2** so that the phase currents **I1** to **I3** for the motor **10** are prevented from sharp

change. The motor driver of FIG. **1** divides the electrical angle 360° of the motor **10** into six, for example, and switches the phases of currents to pass every time period corresponding to the divided electrical angle, that is, every rotation of the rotor of the motor **10** by the angle corresponding to the divided electrical angle, to control the currents to the motor **10**.

For example, a period **TU1** in FIG. **2** is a time period corresponding to the electrical angle 60°. During the period **TU1**, the U-phase current **I1** is a source current having a roughly constant magnitude. The V-phase current **I2** is a sink current of which the magnitude gradually decreases with time **t**. The W-phase current **I3** is a sink current of which the magnitude gradually increases with time **t**. To attain this state, during the period **TU1**, control is performed as follows. The U-phase upper side drive transistor **1** is continuously kept ON. The V-phase and W-phase lower side drive transistors **4** and **6** are repeatedly switched so that the V-phase current **I2** and the W-phase current **I3** behave as shown in FIG. **2**, controlling the ON/OFF periods of the drive transistors **4** and **6**.

FIG. **3** is a block diagram of an example of the torque signal generation circuit **30** in FIG. **1**. The torque signal generation circuit **30** in FIG. **3** includes a both-edge differentiation circuit **31**, constant-current sources **32** and **36**, switches **33** and **37**, capacitors **34** and **38** and level control circuits **35** and **39**.

FIG. **4** is a graph showing signals related to the position detection circuit **22** and the torque signal generation circuit **30**. The position detection circuit **22** determines the position signal **S21** indicating the position of the rotor of the motor **10** based on the Hall sensor outputs **S11** and **S12**. Herein, assume that the position signal **S21** represents the difference between the Hall sensor outputs **S11** and **S12** (S21 = S11 – S12). The Hall sensor outputs **S11** and **S12** are approximate sine waves. When the phase of the Hall sensor output **S11** is ahead of that of the Hall sensor output **S12** by 120°, the phase of the

position signal **S21** is ahead of that of the Hall sensor output **S11** by 30°. Likewise, the position detection circuit **22** determines the position signals **S22** and **S23** from S22 = S12 – S13 and S23 = S13 – S11, for example.

The position detection circuit **22** determines the position signal **PS** based on the determined position signals **S21, S22** and **S23**. The position signal **PS** is a signal having a pulse rising when the position signal **S21** changes from negative to positive and falling when the position signal **S23** changes from positive to negative, a pulse rising when the position signal **S22** changes from negative to positive and falling when the position signal **S21** changes from positive to negative, and a pulse rising when the position signal **S23** changes from negative to positive and falling when the position signal **S22** changes from positive to negative, repeatedly. The timing of the edges of the position signal **PS** matches with the timing at which the waveforms of the Hall sensor outputs **S11, S12** and **S13** cross with each other as shown in FIG. **4**.

The operation of the torque signal generation circuit **30** will be described with reference to FIGS. **3** and **4**. The position signal **PS** is input into the both-edge differentiation circuit **31** from the position detection circuit **22**. The both-edge differentiation circuit **31** outputs a reset pulse signal **S31** to the switch **33** as the control signal. The reset pulse signal **S31** is kept "L" for a constant time period when an edge of the position signal **PS** is detected and otherwise kept "H" ("H" and "L" represent logical high and low potentials, respectively).

The capacitor **34** is connected to one terminal of the constant-current source **32** and connected to a power supply **VCC** via the switch **33** at one terminal, and grounded at the other terminal. The switch **33** is ON only when the reset pulse signal **S31** is "L" so that the capacitor **34** is charged. The capacitor **34** discharges with a current output from the constant-current source **32**.

The capacitor **38** is connected to the output of the constant-current source **36** and grounded via the switch **37** at one terminal, and grounded at the other terminal. The capacitor **38** is charged with a current output from the constant-current source **36**, and the switch **37** is ON only when the reset pulse signal **S31** is "L", permitting discharge of the capacitor **38**. Thus, voltages **S33** and **S34** at the capacitors **34** and **38**, respectively, have the shape of a sawtooth wave as shown in FIG. **4**.

The level control circuit **35** receives the torque command voltage **TI** and the voltage **S33**, generates a signal **TS1** by multiplying the voltage **S33** by a gain so that the peak of the voltage **S33** is equal to the torque command voltage **TI**, and outputs the signal **TS1** to the comparator **51** as a first target signal. Likewise, the level control circuit **39** receives the torque command voltage **TI** and the voltage **S34**, generates a signal **TS2** by multiplying the voltage **S34** by a gain so that the peak of the voltage **S34** is equal to the torque command voltage **TI**, and outputs the signal **TS2** to the comparator **52** as a second target signal, in the same manner.

FIG. **5** is a block diagram of an example of the logic control circuit **40** in FIG. **1**. The logic control circuit **40** in FIG. **5** includes a RS flip-flop **41** as the first latch, a RS flip-flop **42** as the second latch, inverters **44** and **45** and a NAND gate **46**. The inverters **44** and **45** and the NAND gate **46** operate as a logic circuit **49**. FIG. **6** is a graph of input/output signals for the logic control circuit **40** and the comparators **51** and **52** in FIG. **1**. FIG. **7** is a graph showing phase currents in the motor driver of FIG. **1**. FIGS. **6** and **7** show areas at and around time t = t1 in FIGS. **2** and **4** in an enlarged manner.

The operation of the logic control circuit **40** and the currents flowing to the motor **10** will be described with reference to FIGS. **5**, **6** and 7. As shown in FIG. **6**, the reference pulse **PI** is a pulse signal having a roughly constant period, and this period is the reference period for the PWM control. Respective periods of the reference pulse **PI** are also referred

to as PWM control periods.

The reference pulse **PI** is input into the set terminals of the RS flip-flops **41** and **42** shown in FIG. **5**. Upon falling of the reference pulse **PI**, the RS flip-flop **41** is set, turning the control signal **F1** to "H". Then, the output of the logic circuit **49** becomes "L", so that the RS flip-flop **42** is reset, turning the control signal **F2** to "L".

Assume that the phase switch circuit **23** determines that the operation is currently in the period **TU1** in FIG. **2** based on the position signals **S21**, **S22** and **S23**. As shown in FIG. **2**, the period **TU1** is a time period during which the U-phase current **I1** is a source current having a roughly constant magnitude. Since the U-phase current **I1** is the only source current in the period **TU1**, the phase switch circuit **23** puts the drive transistor **1** in the continuous ON state. The V-phase and W-phase currents **I2** and **I3** are sink currents and the magnitudes thereof must be changed. Therefore, the phase switch circuit **23** repeatedly switches the drive transistors **4** and **6** according to the control signals **F1** and **F2**. During the period **TU1**, the phase switch circuit **23** turns ON the drive transistor **4** when the control signal **F1** becomes "H", and turns ON the drive transistor **6** when the control signal **F2** becomes "H". The drive transistors **2**, **3** and **5** are put in the OFF state.

When the control signals **F1** and **F2** become "H" and "L", respectively, the phase switch circuit **23** turns ON the drive transistor **4** (first period **T1**). In this state, a current flows from the drive transistor **1** toward the U-phase coil **11** as a source current. The current flowing through the U-phase coil **11** flows toward the drive transistor **4** via the V-phase coil **12** as sink currents.

In the above state where the drive transistor **4** is ON, the V-phase current **I2** flowing through the V-phase coil **12** flows through the current detection resistance 7. The magnitude of the current flowing through the current detection resistance **7** is equal to that of the U-phase current **I1** flowing through the U-phase coil **11**. At the current detection

resistance 7, generated is a voltage proportional to the magnitude of the current flowing through the current detection resistance 7, and the amplifier **27** outputs the generated voltage to the negative input terminal of the comparator **51** as the motor current detection signal **MC**.

Since the U-phase coil **11**, the V-phase coil **12** and the W-phase coil **13** are inductive loads, the V-phase current **I2** gradually increases during the period **T1** after the conduction of the drive transistor **4** (see FIG. 7). This also gradually increases the motor current detection signal **MC**. Once the voltage of the motor current detection signal **MC** reaches the voltage of the signal **TS1** (see FIG. **6**), the comparator **51** changes the output **CP** to "L". This causes the RS flip-flop **41** to be reset and reverse the output thereof to "L". The control signal **F1** therefore becomes "L". This causes the RS flip-flop **42** to be set and reverse the control signal **F2** to "H". The operation then shifts to the second period **T2**.

During the period **T2**, the control signals **F1** and **F2** are "L" and "H", respectively. Therefore, the phase switch circuit **23** turns OFF the drive transistor **4** and turns ON the drive transistor **6**. With the drive transistor **4** turned OFF, a regenerative current from the V-phase coil **12** flows through the diode **3D**, connected between the source and drain of the drive transistor **3**, and the drive transistor **1**. This V-phase current **I2** flowing as a regenerative current gradually decreases (see FIG. 7). During this period, only the current flowing through the W-phase coil **13** flows to the current detection resistance 7. This enables detection of the current flowing through the W-phase coil **13** without influence of the current flowing through the V-phase coil **12**.

During the period **T2**, the drive transistors **1** and **6** are ON. Therefore, the current flowing through the W-phase coil **13** continues increasing (see FIG. 7), and thus the current flowing to the current detection resistance 7 also continues increasing. The voltage

of the motor current detection signal **MC** therefore increases, and when it reaches the voltage of the signal **TS2** output from the torque signal generation circuit **30**, the comparator **52** changes the output **CP2** to "L". This causes the RS flip-flop **42** to be reset, and turns the control signal **F2** to "L". The operation then shifts to period **T3**.

During the period **T3**, in which both the control signals **F1** and **F2** are "L", the phase switch circuit **23** turns OFF the drive transistors **4** and **6**.

As described above, the drive transistor **4** is ON when the control signal **F1** is "H", and the drive transistor **6** is ON when the control signal **F2** is "H". During the period **T1** in which the control signals **F1** and **F2** are "H" and "L", respectively, the current flowing through the V-phase coil **12** is controlled to be a value corresponding to the signal **TS1**. During the period **T2** in which the control signals **F1** and **F2** are "L" and "H", respectively, the current flowing through the W-phase coil **13** is controlled to be a value corresponding to the signal **TS2**.

In other words, out of the drive transistors of the two phases (V phase and W phase) repeatedly switched during the period **TU1**, the drive transistor **4** of the phase (V phase) for which the current should be decreased during the period **TU1** is turned ON first. When the transistor **4** is turned OFF, the drive transistor **6** of the phase (W phase) for which the current should be increased is turned ON at the same time. (see FIG. **2**). Alternatively, the drive transistor **6** of the W phase may be turned ON first, and the drive transistor **4** of the V phase may be turned ON simultaneously with turning OFF of the transistor **6**.

During the period **T3** in which both the control signals **F1** and **F2** are "L", only regenerative currents flow through the coils **11** to **13**. The V-phase current **I2** and the W-phase current **I3** flowing as regenerative currents gradually decrease (see FIG. 7). Once the reference pulse **PI** is input into the logic control circuit **40**, both the control signals **F1**

and **F2** become "H" and "L", respectively, and the operation described above is repeated.

FIG. **8** is an illustration of routes of the currents flowing to the motor **10** during the period **T1**. Referring to FIG. **8**, during the period **T1**, the V-phase current **I2** flowing through the V-phase coil **12** follows the route from the power supply through the drive transistor **1**, the U-phase coil **11**, the V-phase coil **12**, the drive transistor **4** and the current detection resistance **7**. The W-phase current **I3** flowing through the W-phase coil **13** is a regenerative current following in a loop through the drive transistor **1**, the U-phase coil **11**, the W-phase coil **13** and the diode **5D**. Therefore, only the V-phase current **I2** can be detected from the voltage generated at the current detection resistance **7**.

FIG. **9** is an illustration of routes of the currents flowing to the motor **10** during the period **T2**. Referring to FIG. **9**, during the period **T2**, the V-phase current **I2** flowing through the V-phase coil **12** is a regenerative current flowing in a loop through the drive transistor **1**, the U-phase coil **11**, the V-phase coil **12** and the diode **3D**. The W-phase current **I3** flowing through the W-phase coil **13** follows the route from the power supply through the drive transistor **1**, the U-phase coil **11**, the W-phase coil **13**, the drive transistor **6** and the current detection resistance **7**. Therefore, only the W-phase current **I3** can be detected from the voltage generated at the current detection resistance **7**.

FIG. **10** is an illustration of routes of the currents flowing to the motor **10** during the period **T3**. Referring to FIG. **10**, during the period **T3**, the V-phase current **I2** flowing through the V-phase coil **12** is a regenerative current flowing in a loop as in FIG. **9**. The W-phase current **I3** flowing through the W-phase coil **13** is also a regenerative current flowing in a loop as in FIG. **8**. Therefore, no current flows to the current detection resistance **7**. As described above, two types of currents, that is, a drive current flowing by the conduction of a drive transistor of the output circuit for a phase, and a regenerative current flowing via a diode of the output circuit for the phase, flow alternately through the

corresponding one of the coils **11** to **13**.

Next, the operation of the motor driver of FIG. **1** during a period **TU2** in FIG. **2** will be described. As shown in FIG. **2**, the period **TU2** is a period during which the U-phase current **I1** is a sink current having a roughly constant magnitude. Since the U-phase current **I1** is the only sink current in the period **TU2**, the phase switch circuit **23** puts the drive transistor **2** in the continuous ON state. The V-phase and W-phase currents **I2** and **I3** are source currents and the magnitudes thereof must be changed. Therefore, the phase switch circuit **23** repeatedly switches the drive transistors **3** and **5**. During the period **TU2**, the phase switch circuit **23** turns ON the drive transistor **3** when the control signal **F1** becomes "H", and turns ON the drive transistor **5** when the control signal **F2** becomes "H". The drive transistors **1**, **4** and **6** are put in the OFF state.

When the control signals **F1** and **F2** become "H" and "L", respectively, the phase switch circuit **23** turns ON the drive transistor **3** and turns OFF the drive transistor **5**. When the control signals **F1** and **F2** are "L" and "H", respectively, the drive transistor **3** is turned OFF and the drive transistor **5** is turned ON. When both the control signals **F1** and **F2** are "L", both the drive transistors **3** and **5** are turned OFF.

As a result, during the period **TU2**, the directions of the flows of the U-phase current **I1**, the V-phase current **I2** and the W-phase current **I3** are reverse to those of the flows during the period **TU1**. The other aspects are substantially the same as those during the period **TU1**, and thus detailed description is omitted here.

The operations of the motor driver of FIG. **1** during periods **TV1** and **TW1** are the same as that during the period **TU1**, except for the following. During the period **TV1** in which the V-phase current **I2** is a source current having a roughly constant magnitude, the phase switch circuit **23** puts the drive transistor **3**, in place of the drive transistor **1**, in the continuous ON state. Also, the phase switch circuit **23** repeatedly switches the drive

transistors **6** and **2**, in place of the drive transistors **4** and **6**, respectively, and puts the drive transistors **1**, **4** and **5** in the OFF state.

During the period **TW1** in which the W-phase current **I3** is a source current having a roughly constant magnitude, the phase switch circuit **23** puts the drive transistor **5**, in place of the drive transistor **1**, in the continuous ON state. Also, the phase switch circuit **23** repeatedly switches the drive transistors **2** and **4**, in place of the drive transistors **4** and **6**, respectively, and puts the drive transistors **1**, **3** and **6** in the OFF state.

The operations of the motor driver of FIG. **1** during periods **TV2** and **TW2** are the same as that during the period **TU2**, except for the following. During the period **TV2** in which the V-phase current **I2** is a sink current having a roughly constant magnitude, the phase switch circuit **23** puts the drive transistor **4**, in place of the drive transistor **2**, in the continuous ON state. Also, the phase switch circuit **23** repeatedly switches the drive transistors **5** and **1**, in place of the drive transistors **3** and 5, respectively, and puts the drive transistors **2**, **3** and **6** in the OFF state.

During the period **TW2** in which the W-phase current **I3** is a sink current having a roughly constant magnitude, the phase switch circuit **23** puts the drive transistor **6**, in place of the drive transistor **2**, in the continuous ON state. Also, the phase switch circuit **23** repeatedly switches the drive transistors **1** and **3**, in place of the drive transistors **3** and **5**, respectively, and puts the drive transistors **2**, **4** and **5** in the OFF state.

In this embodiment, the electrical angle 360° of the motor **10** was divided into six parts and the time period corresponding to each part was used as a unit for the control. Alternatively, the electrical angle may be divided into 12 parts, for example, to switch the ON-phase every shorter time period.

There may be cases where the PWM controls of all the phases are not completed within one period of the reference pulse **PI**, i.e., the reference pulse **PI** is input before all

the drive transistors for switching are turned OFF. These cases occur if the repetition frequency of the reference pulse **PI** is inappropriately set. Therefore, the logic control circuit **40** is preferably configured such that upon receipt of the reference pulse **PI**, all the drive transistors for switching are temporarily turned OFF first and then switching operation is initiated. Then, it is possible to prevent shoot-through current from flowing through drive transistors connected in series.

As described above, according to the motor driver of this embodiment, the phase currents **I1** to **I3** for the motor **10** can be controlled to have a roughly trapezoidal waveform having an amplitude corresponding to the torque command voltage **TI** as shown in FIG. **2**. Therefore, the changes of the phase currents at the phase switches can be made mild.

In PWM control of three phase currents, three current detection resistances are normally required. In the motor driver of this embodiment, however, the three phase currents can be controlled with only one current detection resistance, and thus PWM control without a variation in magnitude of the phase currents is possible. In addition, with the reduced number of current detection resistances, the scale of the device can be reduced.

EMBODIMENT 2

FIG. **11** is a block diagram of a motor driver according to a second embodiment of the present invention. The motor driver of FIG. **11** is a driver in which the ON-period control section **100** of the motor driver shown in FIG. **1** is replaced with an ON-period control section **200**. The other components of the motor driver of this embodiment are the same as those described with reference to FIG. **1**. Therefore, these components are denoted by the same reference numerals and the description thereof is omitted here.

The ON-period control section **200** includes a torque signal generation circuit **230**,

a triangular-wave generator **60**, error amplifiers **71** and **72**, comparators **75** and **76** and an offset-added limiting circuit **80**.

FIG. **12** is a circuit diagram showing an example of a configuration of the offset-added limiting circuit **80**. The offset-added limiting circuit **80** includes an operation amplifier **81** and an offset-setting voltage source **82**. The offset-setting voltage source **82** is connected between an input terminal of the offset-added limiting circuit **80** and a positive input terminal of the operation amplifier **81**. Another positive input terminal of the operation amplifier **81** serves as another input terminal of the offset-added limiting circuit **80**. One of the input signals input to the offset-added limiting circuit **80** is output as a slice level signal **SU** without change. The operation amplifier **81** outputs a slice level signal **SL**.

FIG. **13** is a graph showing phase currents and a signal for the ON-period control section **200** in the motor driver of FIG. **11**. FIG. **13** shows areas at and around time t = t1 in FIGS. **2** and **4** in an enlarged manner. The operation of the ON-period control section **200** and the current flowing in the motor **10** will be described with reference to FIGS. **11** and **13**.

As the torque signal generation circuit **30**, the torque signal generation circuit **230** generates torque signals for two phases according to a torque command voltage and outputs the torque signals to the error amplifiers **71** and **72**, respectively. The error amplifiers **71** and **72** have a function of sampling and holding a signal output from the amplifier **27**, e.g., the value of the output from the amplifier **27** immediately before the end of a period in which a current flows to the current detection resistance 7. Each of the error amplifiers **71** and **72** amplifies the difference between the torque signals for respective phases input thereto and the output of the amplifier **27**, and outputs the resultant signal to the offset-added limiting circuit **80**.

The offset-added limiting circuit **80** outputs the first and second slice level signals **SU** and **SL** to the comparators **75** and **76**, respectively, according to the outputs of the error amplifiers **71** and **72**. The slice level signal **SU** is a signal which decreases as the torque command voltage **T1** increases, whereas the slice level signal **SL** is a signal which increases as the torque command voltage **T1** increases

The triangular-wave generator **60** generates a triangular wave **SA** having a roughly constant period as shown in FIG. **13** and outputs the triangular wave **SA** to the comparators **75** and **76**. The comparator **75** outputs, as a switching control signal **F2**, "H" if the triangular wave **SA** is higher than the slice level signal **SU**, and otherwise "L", to a phase switch circuit **23**. The comparator **76** outputs, as a switching control signal **F1**, "H" if the slice level signal **SL** is higher than the triangular wave **SA**, and otherwise "L", to a phase switch circuit **23**.

The offset-added limiting circuit **80** limits the levels of the slice level signals **SU** and **SL** with an offset provided therebetween such that the slice level signal **SU** is always higher than the slice level signal **SL**, and outputs the slice level signals **SU** and **SL**. Therefore, the periods in which the control signal **F2** output from the comparator **75** is "H" and the periods in which the control signal **F1** output from the comparator **76** is "H" can be made not to overlap with each other. Accordingly, as in the first embodiment, a plurality of phase currents are not flown to the current detection resistance 7 at the same time.

In this manner, in the motor driver of this embodiment, the changes of the phase currents at the phase switches can be made mild, and in addition, three phase currents can be controlled with only one current detection resistance.

EMBODIMENT 3

In the foregoing embodiments, the drive of the 3-phase motor with phase currents

having trapezoidal waveforms was described. However, the phase currents do not necessarily have trapezoidal waveforms and may be sine waves or may have other waveforms. The present invention is not limited to the drive of the 3-phase motor and is applicable to the drive of a motor of an even number of phases that is four or more. Hereinafter, the case where phase currents have waveforms other than trapezoidal waveforms will be described. In this embodiment, a modified form of the motor driver shown in FIG. **1** is used.

FIG. **14** is a graph showing waveforms of output currents of respective phases in driving a 3-phase motor such that the phase currents are sine waves. In order to achieve such operation as shown in FIG. **14**, it is sufficient for the output of the torque generation circuit **30** in FIG. **1** to have the shape of a sine wave instead of the shape of a sawtooth wave as shown in FIG. **4**. Specifically, it is sufficient to use a signal with repetition of waveforms in the range from 0° to 60° of the phase of a sine wave as a signal **TS2**, and a signal with repetition of waveforms in the range from 120° to 180° of the phase of a sine wave as a signal **TS1**.

In this case, the magnitude of the W-phase current, for example, is equal to the sum of the other two phase currents (the U-phase current and the V-phase current) which are shifted from the W-phase current by 120°, and the direction of the W-phase current is opposite to the direction of the other two phase currents.

FIG. **15** is a graph showing waveforms of output currents of respective phases in driving a 4-phase motor such that the phase currents are sine waves. Although not shown specifically, in the case of the 4-phase drive, it is assumed that the drive transistors and coils for the respective phases in the motor are connected in the following manner.

Specifically, as in the circuit configured by the drive transistors **1** and **2** and the diodes **1D** and **2D** shown in FIG. **1**, the motor driver includes four circuits (half-bridge

circuits) in each of which an upper side drive transistor and a lower side drive transistor are connected in series and diodes are connected to the drain and source of each of the transistors. These four half-bridges correspond to the respective phases and are connected in parallel. One terminal of each of the half-bridges is connected to a power supply **VCC** in common, and the other is connected to a terminal of a current detection resistance in common. The other terminal of the current detection resistance is grounded. The connection point between the upper side drive transistor and the lower side drive transistor in each of the half-bridges is connected to one terminal of one of the coils for the corresponding phase. The other terminals of the respective coils are connected to each other.

In order to achieve such operation of phase currents as shown in FIG. **15**, it is sufficient for the output of the torque generation circuit **30** in FIG. **1** to have the shape of a sine wave instead of the shape of a sawtooth wave as shown in FIG. **4**. Specifically, it is sufficient to use a signal with repetition of waveforms in the range from 0° to 90° of the phase of a sine wave as a signal **TS2**, and a signal with repetition of waveforms in the range from 90° to 180° of the phase of a sine wave as a signal **TS1**.

In driving a motor of an even number of phases, with respect to two phases exhibiting different directions of currents and having substantially the same magnitude (i.e., two phases opposite to each other), it is sufficient to drive an upper side drive transistor for one phase and a lower side drive transistor for the other phase as a pair at the same time. Therefore, control is performed in the same manner as in the case of driving a motor of substantially a half number of phases. That is to say, the 4-phase motor can be operated by the 2-phase sine-wave drive using sine waves of which phases differ from each other by 90° as target values of respective phase currents.

During a period **T41** in FIG. **15**, as the periods **T1** and **T2** in FIG. **6**, time periods in

which a U-phase upper side drive transistor and a W-phase lower side drive transistor are turned ON at the same time and time periods in which a V-phase lower side drive transistor and an X-phase upper side drive transistor are turned ON at the same time are alternately provided.

During the time periods in which the U-phase upper side drive transistor and the W-phase lower side drive transistor are turned ON, currents passing through these drive transistors, a U-phase coil and a W-phase coil flow to the current detection resistance. At this time, the V-phase current and the X-phase current flow as a regenerative current. Since only the U-phase current (W-phase current) flows to the current detection resistance, the U-phase current can be detected, so that feedback control can be performed such that the U-phase and W-phase currents have target values respectively.

During the time periods in which the V-phase lower side drive transistor and the X-phase upper side drive transistor are turned ON, currents passing through these drive transistors, a V-phase coil and an X-phase coil flow to the current detection resistance. At this time, the U-phase current and the W-phase current flow as a regenerative current. Since only the V-phase current (X-phase current) flows to the current detection resistance, the V-phase current can be detected, so that feedback control can be performed such that the V-phase and X-phase currents have target values respectively. In this way, the time periods in which phase currents to be detected flow to the current detection resistance are made not to overlap with the time periods in which the other phase currents flow to the current detection resistance.

In the same manner, during a period **T42**, time periods in which the U-phase upper side drive transistor and the W-phase lower side drive transistor are turned ON at the same time and time periods in which a V-phase upper side drive transistor and an X-phase lower side drive transistor are turned ON at the same time are provided. During a period **T43**,

time periods in which a U-phase lower side drive transistor and a W-phase upper side drive transistor are turned ON at the same time and time periods in which the V-phase upper side drive transistor and the X-phase lower side drive transistor are turned ON at the same time are provided. During a period **T44**, time periods in which the U-phase lower side drive transistor and the W-phase upper side drive transistor are turned ON at the same time and time periods in which the V-phase lower side drive transistor and the X-phase upper side drive transistor are turned ON at the same time are provided. As a result, the 4-phase motor can be driven such that the phase currents are sine waves.

FIG. **16** is a graph showing waveforms of output currents of respective phases in driving a 6-phase motor such that the phase currents are sine waves. Although not shown specifically, in the case of the 6-phase drive, the drive transistors and coils for the respective phases in the motor are connected in the following manner.

Specifically, the motor driver includes six half-bridges. These six half-bridges correspond to the respective phases and are connected in parallel. One terminal of each of the half-bridges is connected to a power supply **VCC** in common, and the other is connected to one terminal of a current detection resistance in common. The other terminal of the current detection resistance is grounded. The connection point between the upper side drive transistor and the lower side drive transistor in each of the half-bridges is connected to one terminal of one of the coils for the corresponding phase. The other terminals of the respective coils are connected to each other.

In order to achieve such operation of phase currents as shown in FIG. **16**, it is sufficient for the output of the torque generation circuit **30** in FIG. **1** to have the shape of a sine wave instead of the shape of a sawtooth wave as shown in FIG. **4**. Specifically, it is sufficient to use a signal with repetition of waveforms in the range from 0° to 60°, 60° to 120° or 120° to 180° of the phase of a sine wave.

In driving the 6-phase motor, which is of an even number of phases as in the case of the 4-phase motor, with respect to two phases exhibiting different directions of currents and having substantially the same magnitude, it is sufficient to drive an upper side drive transistor for one phase and a lower side drive transistor for the other phase as a pair at the same time. Therefore, control is performed in the same manner as in the case of driving a motor of substantially a half number of phases. That is to say, the 6-phase motor can be operated by the 3-phase sine-wave drive using sine waves of which phases differ from each other by 60° as target values of respective phase currents.

During a period **T61** in FIG. **16**, time periods in which a U-phase upper side drive transistor and an X-phase lower side drive transistor are turned ON at the same time, time periods in which a V-phase lower side drive transistor and a Y-phase upper side drive transistor are turned ON at the same time, and time periods in which a W-phase lower side drive transistor and a Z-phase upper side drive transistor are turned ON at the same time are provided in order.

During the time periods in which the U-phase upper side drive transistor and the X-phase lower side drive transistor are turned ON, currents passing through these drive transistors, a U-phase coil and an X-phase coil flow to the current detection resistance. At this time, the currents other than the U-phase and X-phase currents flow as a regenerative current. Since only the U-phase current (X-phase current) flows to the current detection resistance, the U-phase current can be detected, so that feedback control can be performed such that the U-phase and X-phase currents have target values respectively.

During the time periods in which the V-phase lower side drive transistor and the Y-phase upper side drive transistor are turned ON, currents passing through these drive transistors, a V-phase coil and a Y-phase coil flow to the current detection resistance. At this time, the currents other than the V-phase and Y-phase current flow as a regenerative

current. Since only the V-phase current (Y-phase current) flows to the current detection resistance, the V-phase current can be detected, so that feedback control can be performed such that the V-phase and Y-phase currents have target values respectively.

Likewise, during the time periods in which the W-phase lower side drive transistor and the Z-phase upper side drive transistor are turned ON, feedback control can be performed such that the W-phase and Z-phase currents have target values respectively. In this manner, the time periods in which phase currents to be detected flow to the current detection resistance are made not to overlap with the time periods in which the other phase currents flow to the current detection resistance.

In the same manner, during a period **T62**, time periods in which the U-phase upper side drive transistor and the X-phase lower side drive transistor are turned ON at the same time, time periods in which a V-phase upper side drive transistor and a Y-phase lower side drive transistor are turned ON at the same time, and time periods in which the W-phase lower side drive transistor and the Z-phase upper side drive transistor are turned ON at the same time are provided in order.

During a period **T63**, time periods in which the U-phase upper side drive transistor and the X-phase lower side drive transistor are turned ON at the same time, time periods in which the V-phase upper side drive transistor and the Y-phase lower side drive transistor are turned ON at the same time, and time periods in which a W-phase upper side drive transistor and a Z-phase lower side drive transistor are turned ON at the same time are provided in order. Subsequently, during periods **T64** through **T66**, transistors to be turned ON are sequentially switched in the same manner. As a result, the 6-phase motor can be driven such that the phase currents are sine waves.

In driving the 6-phase motor, transistors to be turned ON may be switched in the following manner. That is to say, during the period **T62** shown in FIG. **16**, the U-phase

upper side drive transistor and the X-phase lower side drive transistor are turned ON at the same time. In this period, time periods in which the W-phase lower side drive transistor and the Z-phase upper side drive transistor are turned ON at the same time, and time periods in which the Y-phase lower side drive transistor and the V-phase upper side drive transistor are turned ON at the same time are alternately provided.

During the period **T63**, the V-phase upper side drive transistor and the Y-phase lower side drive transistor are turned ON at the same time. In this period, time periods in which the X-phase lower side drive transistor and the U-phase upper side drive transistor are turned ON at the same time, and time periods in which the Z-phase lower side drive transistor and the W-phase upper side drive transistor are turned ON at the same time are alternately provided.

In the same manner, during the period **T64**, the W-phase upper side drive transistor and the Z-phase lower side drive transistor are turned ON at the same time. In this period, time periods in which the Y-phase lower side drive transistor and the V-phase upper side drive transistor are turned ON at the same time, and time periods in which the U-phase lower side drive transistor and the X-phase upper side drive transistor are turned ON at the same time are alternately provided. Subsequently, during the periods **T65** and **T66**, transistors to be turned ON are sequentially switched in the same manner.

FIG. **17** is a graph showing waveforms of output currents of respective phases in driving an 8-phase motor such that the phase currents are sine waves. Although not shown specifically, in the case of the 8-phase drive, it is assumed that the drive transistors and coils for the respective phases in the motor are connected in the following manner.

Specifically, the motor driver includes eight half-bridges. These eight half-bridges correspond to the respective phases and are connected in parallel. One terminal of each of the half-bridges is connected to a power supply **VCC** in common, and the other is

connected to one terminal of a current detection resistance in common. The other terminal of the current detection resistance is grounded. The connection point between the upper side drive transistor and the lower side drive transistor in each of the half-bridges is connected to one terminal of one of the coils for the corresponding phase. The other terminals of the respective coils are connected to each other.

In order to achieve such operation of phase currents as shown in FIG. **17**, it is sufficient for the output of the torque generation circuit **30** in FIG. **1** to have the shape of a sine wave instead of the shape of a sawtooth wave as shown in FIG. **4**. Specifically, it is sufficient to use a signal with repetition of waveforms in the range from 0° to 45°, 45° to 90°, 90° to 135° or 135° to 180° of the phase of a sine wave.

In driving the 8-phase motor, which is of an even number of phases as in the case of the 4-phase motor, with respect to two phases exhibiting different directions of currents and having substantially the same magnitude, it is sufficient to drive an upper side drive transistor for one phase and a lower side drive transistor for the other phase as a pair at the same time. Therefore, control is performed in the same manner as in the case of driving a motor of substantially a half number of phases. That is to say, the 8-phase motor can be operated by the 4-phase sine-wave drive using sine waves of which phases differ from each other by 45° as target values of respective phase currents.

During a period **T81** in FIG. 17, time periods in which a U-phase upper side drive transistor and a Y-phase lower side drive transistor are turned ON at the same time, time periods in which a V-phase lower side drive transistor and a Z-phase upper side drive transistor are turned ON at the same time, time periods in which a W-phase lower side drive transistor and an A-phase upper side drive transistor are turned ON at the same time, and time periods in which an X-phase lower side drive transistor and a B-phase upper side drive transistor are turned ON at the same time are provided in order.

During the time periods in which the U-phase upper side drive transistor and the Y-phase lower side drive transistor are turned ON, currents passing through these drive transistors, a U-phase coil and a Y-phase coil flow to the current detection resistance. At this time, the currents other than the U-phase and Y-phase currents flow as a regenerative current. Since only the U-phase current (Y-phase current) flows to the current detection resistance, the U-phase current can be detected, so that feedback control can be performed such that the U-phase and Y-phase currents have target values respectively.

During the time periods in which the V-phase lower side drive transistor and the Z-phase upper side drive transistor are turned ON, currents passing through these drive transistors, a V-phase coil and an Z-phase coil flow to the current detection resistance. At this time, the currents other than the V-phase and Z-phase currents flow as a regenerative current. Since only the V-phase current (Z-phase current) flows to the current detection resistance, the V-phase current can be detected, so that feedback control can be performed such that the V-phase and Z-phase currents have target values respectively.

Likewise, during the time periods in which the W-phase lower side drive transistor and the A-phase upper side drive transistor are turned ON at the same time, feedback control can be performed such that the W-phase and A-phase currents have target values respectively. During the time periods in which the X-phase lower side drive transistor and the B-phase upper side drive transistor are turned ON at the same time, feedback control can be performed such that the X-phase and B-phase currents have target values respectively. In this manner, the time periods in which phase currents to be detected flow to the current detection resistance are made not to overlap with the time periods in which the other phase currents flow to the current detection resistance.

In the same manner, during a period **T82**, time periods in which the U-phase upper side drive transistor and the Y-phase lower side drive transistor are turned ON at the same

time, time periods in which a V-phase upper side drive transistor and a Z-phase lower side drive transistor are turned ON at the same time, the W-phase lower side drive transistor and the A-phase upper side drive transistor are turned ON at the same time, and time periods in which an X-phase lower side drive transistor and a B-phase upper side drive transistor are turned ON at the same time are provided in order. Subsequently, during periods **T83** through **T88**, transistors to be turned ON are sequentially switched in the same manner. As a result, the 8-phase motor can be driven such that the phase currents are sine waves.

The case of a motor of an even number of phases that is ten or more can be described in the same manner.

In the third embodiment, a peak current control as described in the first embodiment may be performed, or a PWM control with triangular-wave slicing as described in the second embodiment may be performed.

In the embodiments described above, the motor driver includes the diodes **1D** to **6D**. Alternatively, each of the drive transistors **1** to **6** may include a parasitic diode. In other words, a diode may structurally exist in each of the drive transistors **1** to **6**.

Transistors other than the n-type MOS transistors may be used as the drive transistors **1** to **6**.

In the above embodiments, the current detection resistance **7** was provided between the sources of the lower side transistors **2**, **4** and **6** and the ground. Alternatively, the current detection resistance may be provided between the power supply **VCC** and the drains of the upper side transistors **1**, **3** and **5**.

The Y connection was adopted for the motor in the above embodiments. Alternatively, delta connection may be adopted.

The order of the three phases of the phase currents from ahead to behind was the U

phase, the V phase and the W phase. The present invention is also applicable to the case of adopting the order of the W phase, the V phase and the U phase to reverse the rotation of the motor.

The Hall sensors were used for position detection in the above description. However, use of Hall sensors is not necessarily a requisite. For example, a CR filter circuit may be provided for each of the U, V and W phases, to filter a harmonic content of a PWM drive current. The output of the filter and a reference voltage (i.e., a potential at a connection point of three Y-connected coils) of the motor may be compared for each phase, to detect the position of a rotor of the motor. However, in consideration of malfunction that may occur due to the harmonic content of the PWM drive current, use of Hall sensors is more advantageous.

In addition, synchronous rectification operation can be performed under synchronous operation by inverting the phase of a transistor other than a transistor in the ON state between each pair of drive transistors connected in series constituting a half-bridge.

Further, the motor may be driven without using any sensor. That is to say, a drive transistor of a phase is turned OFF at and around a zero-cross point at which the direction of a phase current for the phase is switched, and a mask period in which the phase current is zero is provided to detect a counter electromotive force within the period, thereby obtaining a signal about a rotor position. Application of a torque command signal for setting the phase current at zero before and after the mask period prevents the phase current from changing sharply in a shift to the mask period, and thus vibration of the motor and electromagnetic noise during the phase switch can be reduced also in the sensorless motor.

In the above embodiments, one detection resistance was provided. Alternatively,

two or more detection resistances may be provided if a plurality of phases are used. That is to say, in the case of eight phases, for example, two detection resistances may be provided so that drive transistors for four phases are connected to one of the detection resistances in common and the drive transistors for the other phases are connected to the other detection resistance in common. Then, the motor is relieved from the restriction that a phase utilizing one of the detection resistances must utilize the regenerative period of a phase utilizing the other detection resistance, so that the maximum duty of the PWM control can be increased.

Thus, according to the motor driver of the present invention, the phase currents are prevented from sharp change, and thus vibration of the motor and generation of noise during phase switch can be suppressed. Since the number of current detection resistances to be used is smaller than the number of phases, the scale of the device can be reduced.